

Automated Spacecraft Scheduling

The ASTER Example

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Ground System Architectures Workshop 2002

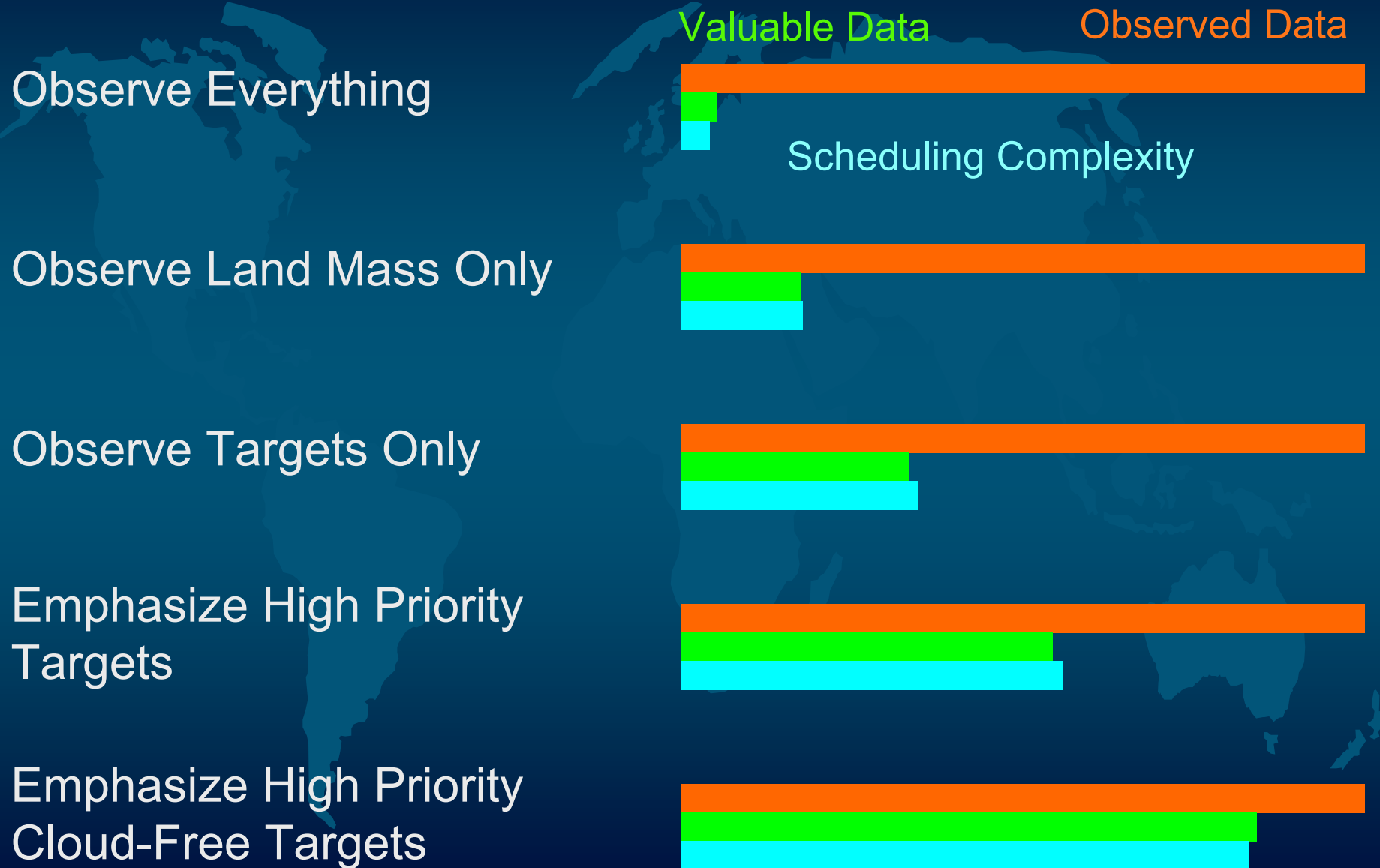


Jet Propulsion Laboratory

The Concept

- Scheduling by software instead of humans
- Ideally suited to orbital observing missions
- Rationale:
 - Increased target data return
 - Lower cost
- Now operating on ASTER / Terra (EOS-AM1)

Some Targeting Options for Earth Observing Missions



Maximum Performance

Used Capability

Maximum
Valuable Data
Return

Valuable Data

Maximize: $\frac{\text{Used Capability}}{\text{Total Capability}}$ and $\frac{\text{Valuable Data}}{\text{Observed Data}}$

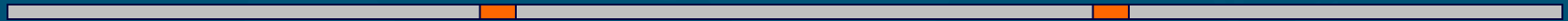
Conventional Human Scheduling

- Select high priority targets
- Check the weather report
 - Avoid clouds
- Calculate observation times, pointing angles, etc.
 - Software tools
 - Groundtrack grid charts
- Generate command sequences
- Check constraints
 - OR always stay well within limits



Questions...

- What is the workforce cost of manually creating schedules?
- What is the workforce cost of adjudicating between competing requesters? (*and career cost?*)
- What about all that “slack” time?

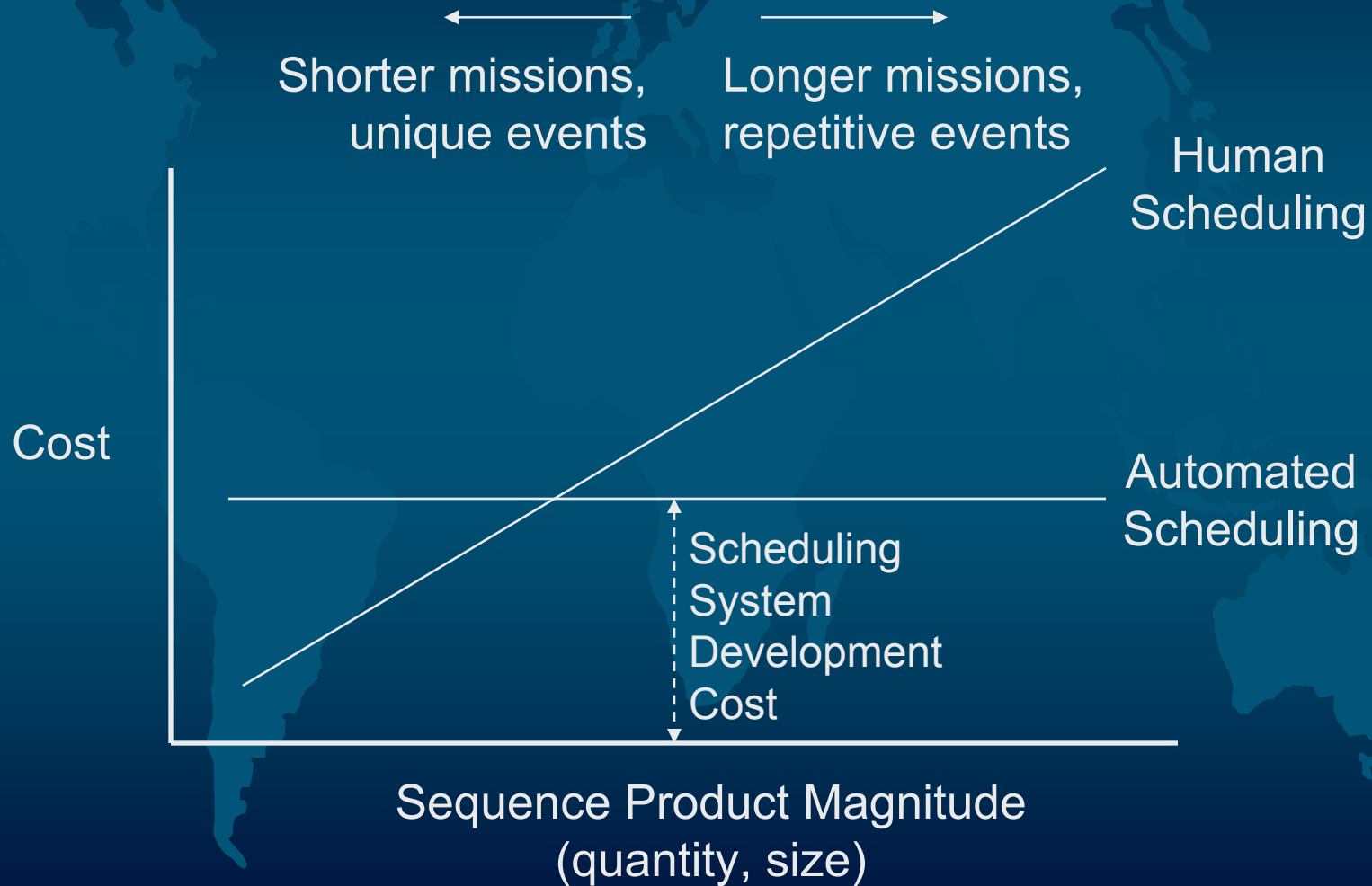


- Are we fully utilizing spacecraft capability?
 - Manually optimizing schedules is expensive
 - Cassini sequences require work-years

Automated Scheduling

- Automatic:
 - Target prioritization
 - Schedule creation
 - Constraint checking
- Humans are elevated to a higher level
 - Humans set goals, software handles the details
 - Can still “joystick” the spacecraft
 - Input desired activity with high priority
- Compared to conventional scheduling:
 - More optimal (maximizes capability used and valuable data)
 - Faster
 - Lower cost
 - Safer

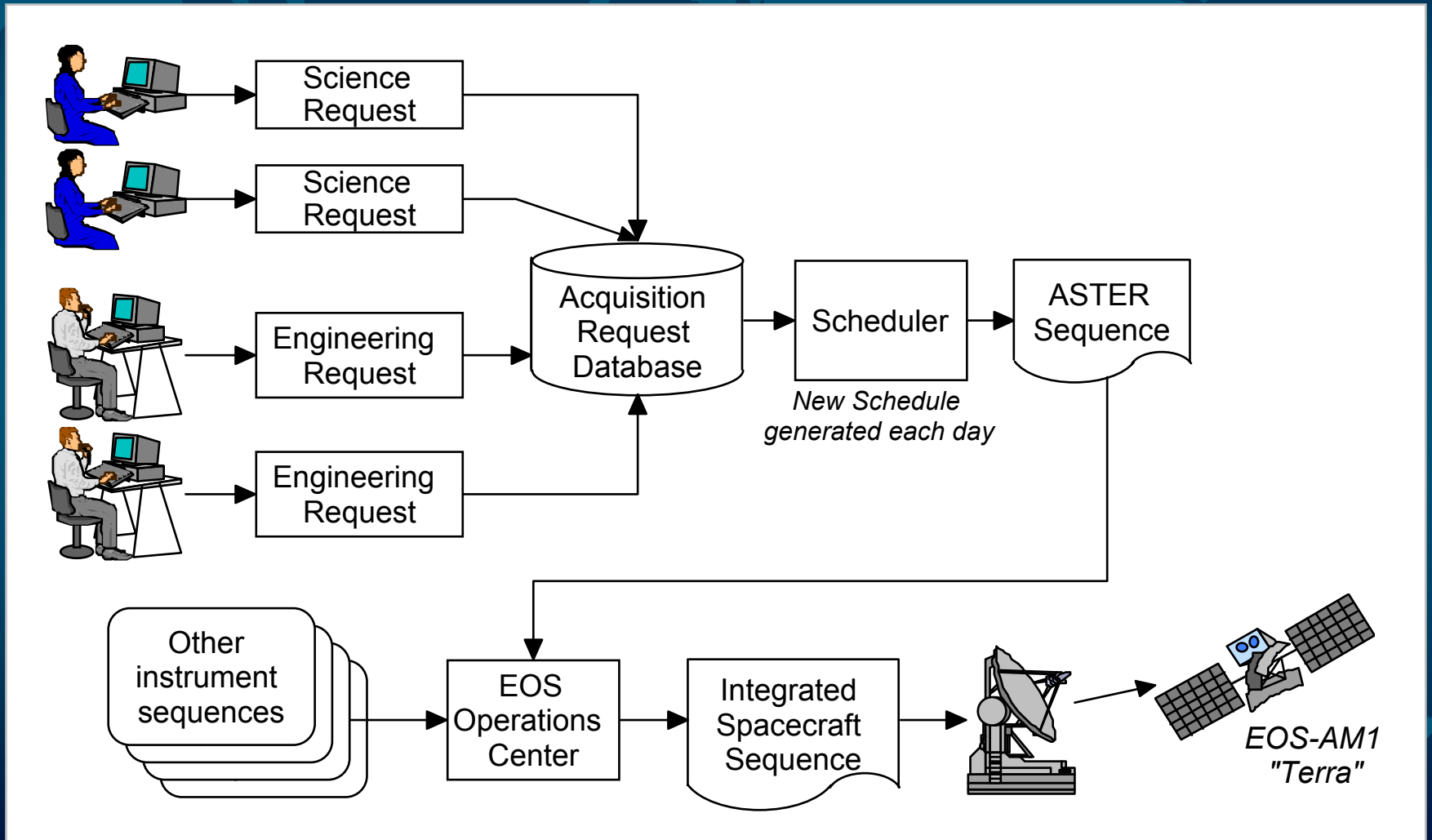
When is Automated Scheduling Appropriate?



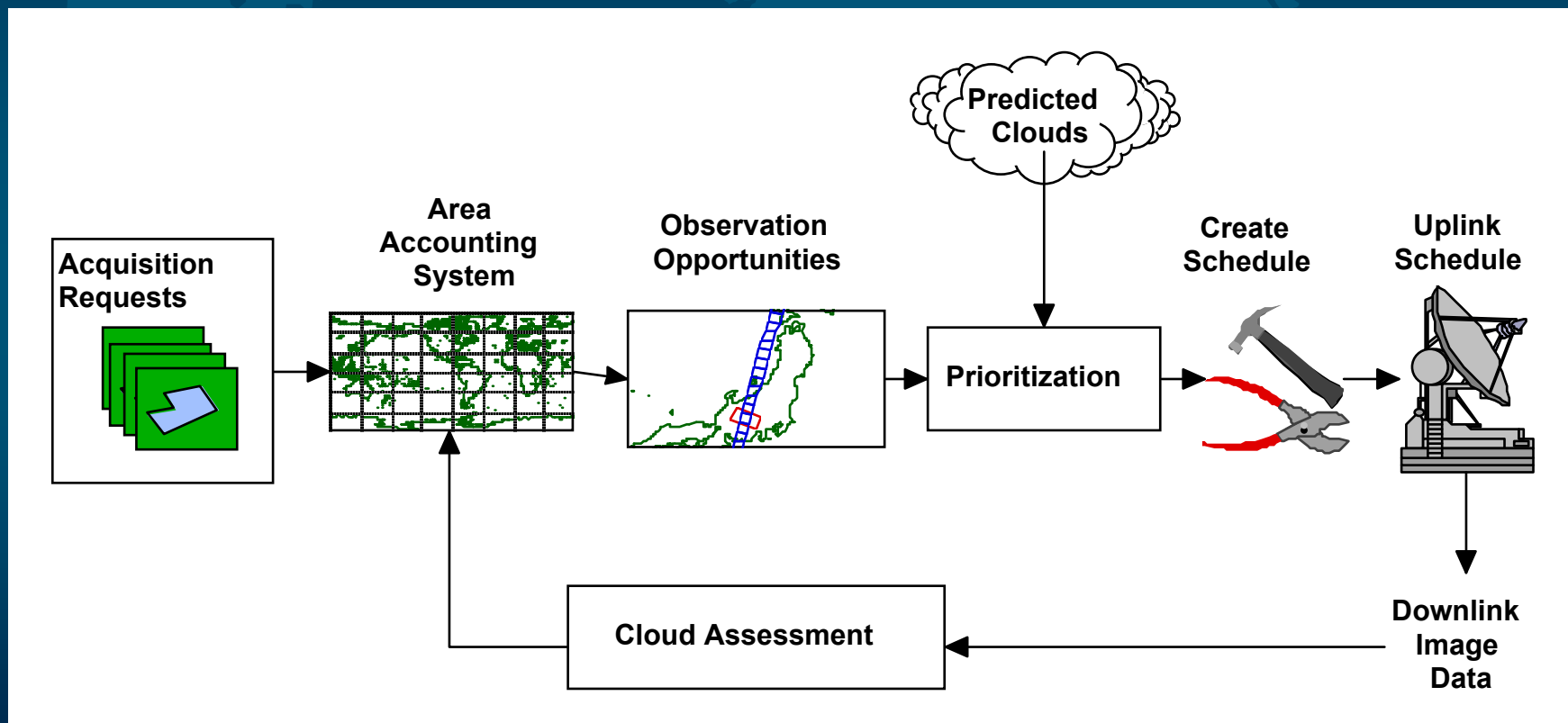
The ASTER Example

- Advanced Spaceborne Thermal Emission and Reflection Radiometer
- Built by Japan MITI/JAROS
- Currently operating on NASA Terra (EOS-AM1)
- Multiple telescopes, visual through thermal infrared
- Polar orbit, 16-day groundtrack repeat cycle
- Crosstrack pointing +/- 24 deg
- 60 km observation swath
- 10 m resolution in visible channels
- Many observation modes and settings
- Observations highly constrained by data, power, and thermal limits
- Many competing users

ASTER Uplink Process

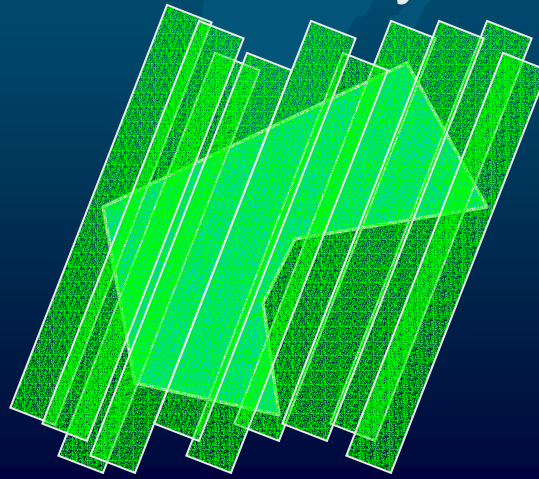


ASTER Scheduling Process



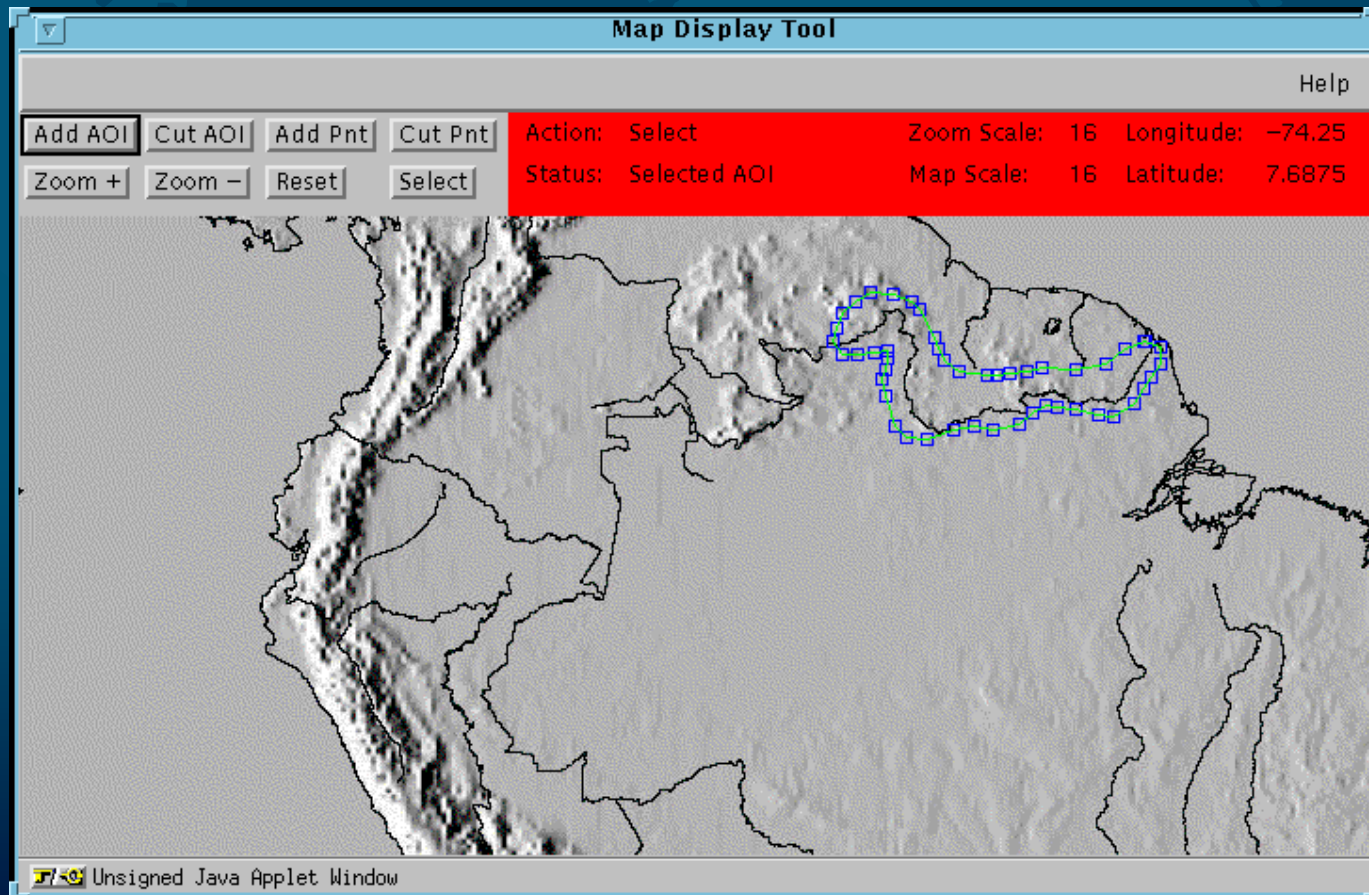
ASTER Acquisition Requests

- User specifies:
 - Polygonal target Area of Interest (AOI)
 - Instrument mode & settings
 - Requirements on timing, lighting, repeat obs, etc.
- Request is fulfilled over time
 - Generally multiple observations
 - AOI can be much larger than observation swath
 - Cloudy areas automatically reobserved



ASTER Acquisition Requests (xARs)

Area of Interest



ASTER Acquisition Requests (xARs)

Netscape: STAR Editor

Date and Time

- Define or modify Timing Requirements using Year, Month or Day buttons.
- Do not edit the date text fields directly. Such edits are ignored.
- Additional parameters are available through the *Detailed Mode* button. [Help with Timing Requirements](#)

STAR Lifetime Start	STAR Lifetime End
Sat, 2 Feb 2002 0:0:0 GMT	Sat, 2 Feb 2002 0:0:0 GMT
Year: <input type="button" value="+"/> <input type="button" value="-"/> Month: <input type="button" value="+"/> <input type="button" value="-"/> Day: <input type="button" value="+"/> <input type="button" value="-"/>	Year: <input type="button" value="+"/> <input type="button" value="-"/> Month: <input type="button" value="+"/> <input type="button" value="-"/> Day: <input type="button" value="+"/> <input type="button" value="-"/>

[Require Multiple Observations:](#) ☐ Yes ☒ No

[Acquisition Window Duration \(Days\):](#)

[Acquisition Window Repeat Cycle:](#)

• Choose from one of the following: or

Send comments to Dale Noss, noss@east.la.asu.edu

Area Of Interest
Date & Time
Identification
Misc.
Parameters
Telescopes
STAR Summary
Help

ASTER Acquisition Requests (xARs)

Netscape: STAR Editor

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Telescopes

- Define or modify Telescope configurations and gains.
- Push *Basic Mode* to access basic telescope parameters. [Help with telescopes and gains](#)
- Select from one of five [telescope configurations](#).
 - ☒ Full Mode: Use all telescope bands. *Set gains for all VNIR and SWIR bands.*
 - ☐ Use VNIR (Nadir + Stereo). *Set gains for all VNIR bands.*
 - ☐ Use V3B/ V3N Stereo. *Set gains for VNIR 3 (Nadir & Back).*
 - ☐ Use SWIR and TIR. *Set gains for all SWIR bands.*
 - ☐ Use TIR. *No gain setting.*
- Set the gains for the appropriate bands.
 - VNIR Band 1 Gain:
 - VNIR Band 2 Gain:
 - VNIR Bands 3 Nadir and 3 Back Gain:
 - SWIR Bands 4-9 Gains
 - Band 4: Band 5: Band 6:
 - Band 7: Band 8: Band 9:
- Choose from one of the following: , or

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Identification

• Define or modify STAR identification parameters. [Help with STAR Identification](#)

STAR Identification	
STAR Title: 32 chars	<input type="text"/>
STAR Type:	Regional STAR, low-priority
Investigation Class:	Land: Geology, solid Earth geophysics
Ground Campaign:	<input type="radio"/> Yes <input checked="" type="radio"/> No
Scientific Objective: 32 chars	<input type="text"/>
Requester Comments: 255 chars	<input type="text"/>

• Choose from one of the following: , or

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Miscellaneous STAR Parameters

- Define or modify STAR parameters.
- Push *Basic Mode* to access basic xar parameters. [Help with STAR Parameters](#)

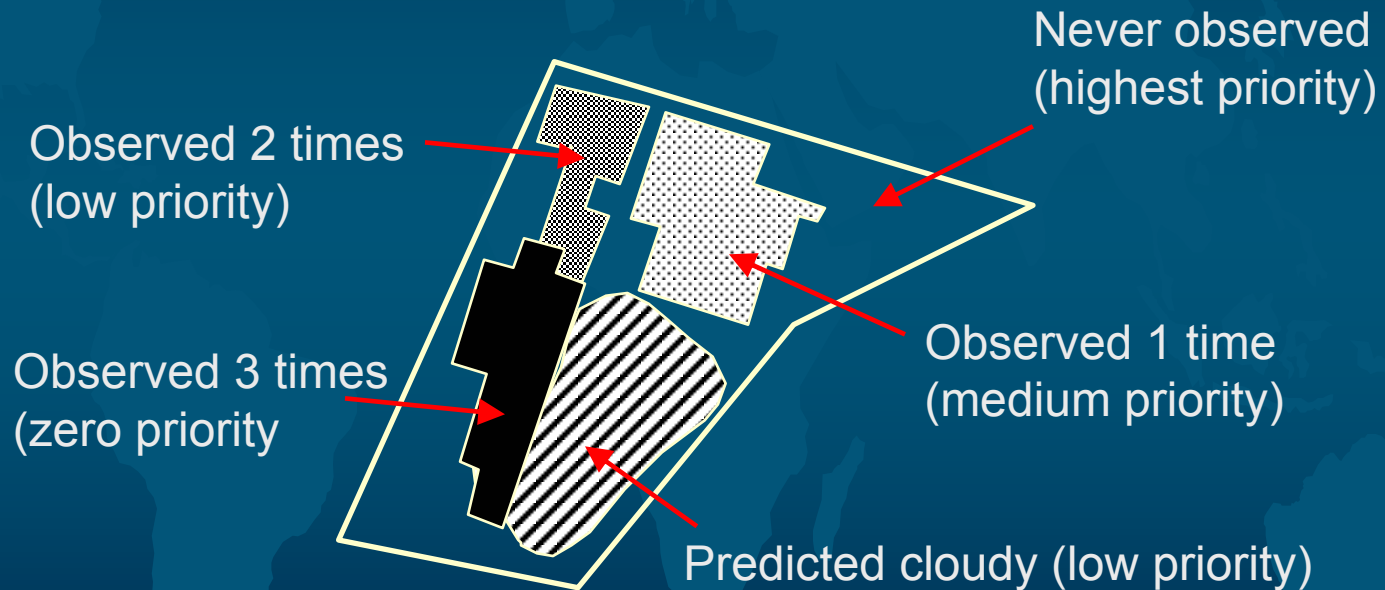
Require Expedited Data: <input type="radio"/> Yes <input checked="" type="radio"/> No	Justification: <input type="text"/> <small>128 chars</small>	
Generate Level 1B Product: <input type="radio"/> Yes <input checked="" type="radio"/> No	Map Projection: UTM	Resampling: Cubic Convolution
Use Specific View Swath: <input type="radio"/> Yes <input checked="" type="radio"/> No	Specific View Swath ID: <input type="text" value="4"/>	
Use Specific Look Angle: <input type="radio"/> Yes <input checked="" type="radio"/> No	Specific Look Angle: <input type="text" value="0"/>	Look Angle Range Min: <input type="text" value="-8.55"/> , Max: <input type="text" value="8.55"/>
Mirror Look Angle Range Across Nadir: <input checked="" type="radio"/> Yes <input type="radio"/> No		
Avoid Clouds: <input checked="" type="radio"/> Yes <input type="radio"/> No	Maximum Acceptable Percent Cloud Coverage: <input type="text" value="20"/>	
Sun Angle Constraints:	Minimum: <input type="text" value="0.00"/>	Maximum: <input type="text" value="90.00"/>
AOI Coverage Method: <input checked="" type="radio"/> Normal <input type="radio"/> Sampled	Sample Length (Scenes): Min: <input type="text" value="1"/> , Max: <input type="text" value="1"/> Minimum Acceptable Percent Coverage: <input type="text" value="100.00"/> Minimum Number of Samples: <input type="text" value="1"/>	
Day/Night Observations:	<input checked="" type="radio"/> Day <input type="radio"/> Night <input type="radio"/> Day or Night	
Implementation Urgency:	<input type="radio"/> Urgent <input checked="" type="radio"/> Normal	
Allow Cross-Track Fragmentation:	<input checked="" type="radio"/> Yes <input type="radio"/> No	
Require Full Duration Observations Across AOI:	<input type="radio"/> Yes <input checked="" type="radio"/> No	

Choose from one of the following: or

Area Of Interest
Date & Time
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Telescopes
STAR Summary
Help

Prioritization: Priority Varies With Position, Time, Cloudiness, Etc.

Example: 3 repeat observations requested



Data maintained globally in 1 km² pixels in GIS

Prioritization: Observation Swaths

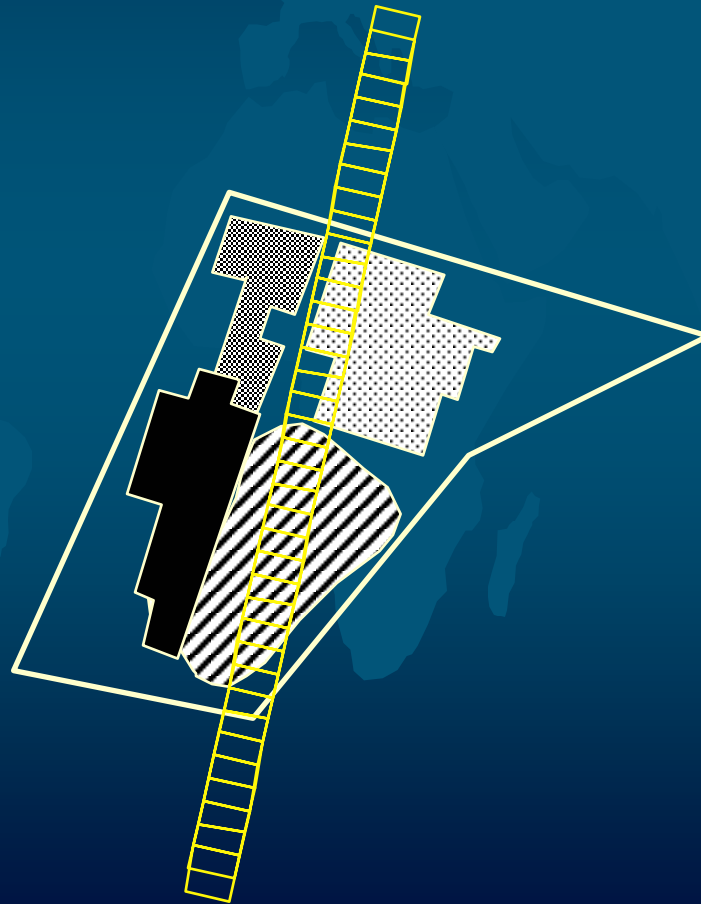
Potential Observation Swath
on Planet Surface

Time



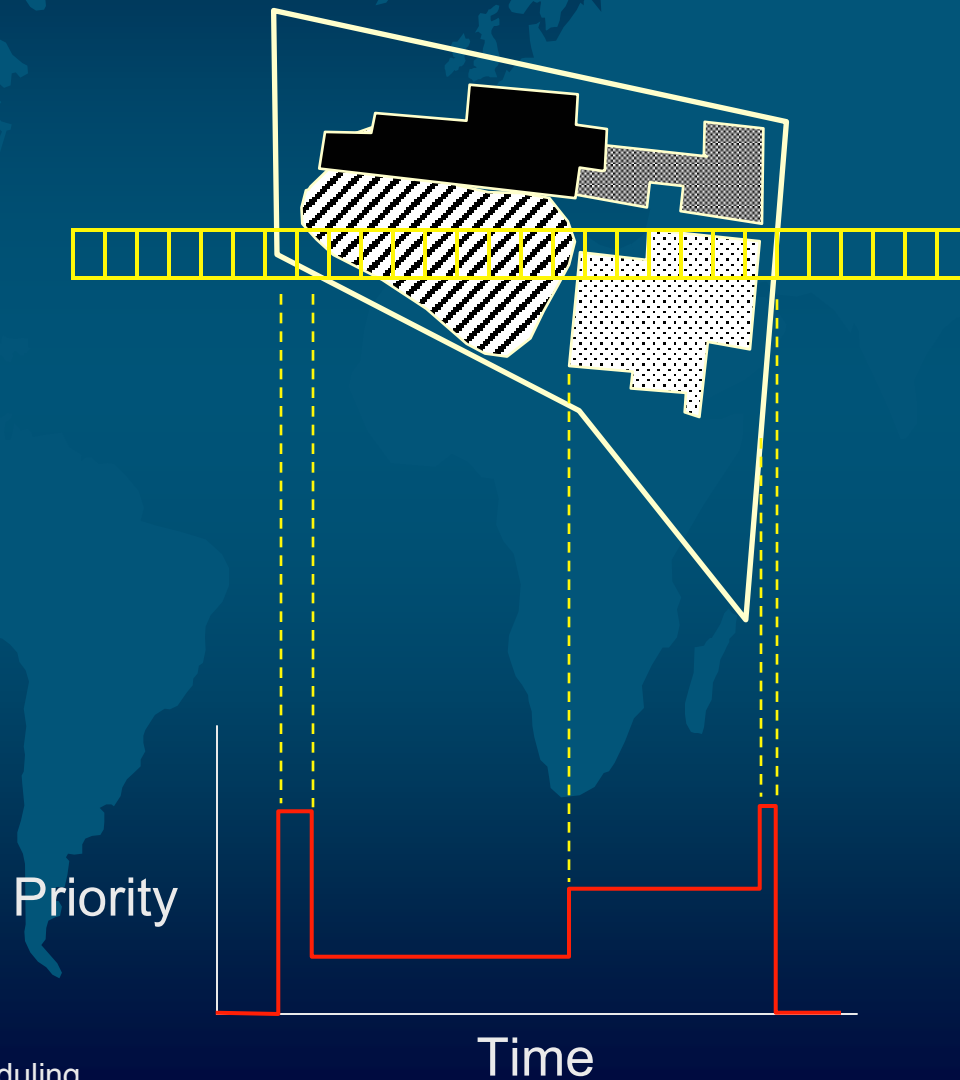
Prioritization Process

Overlay potential observation swath onto planet surface:



Prioritization Process

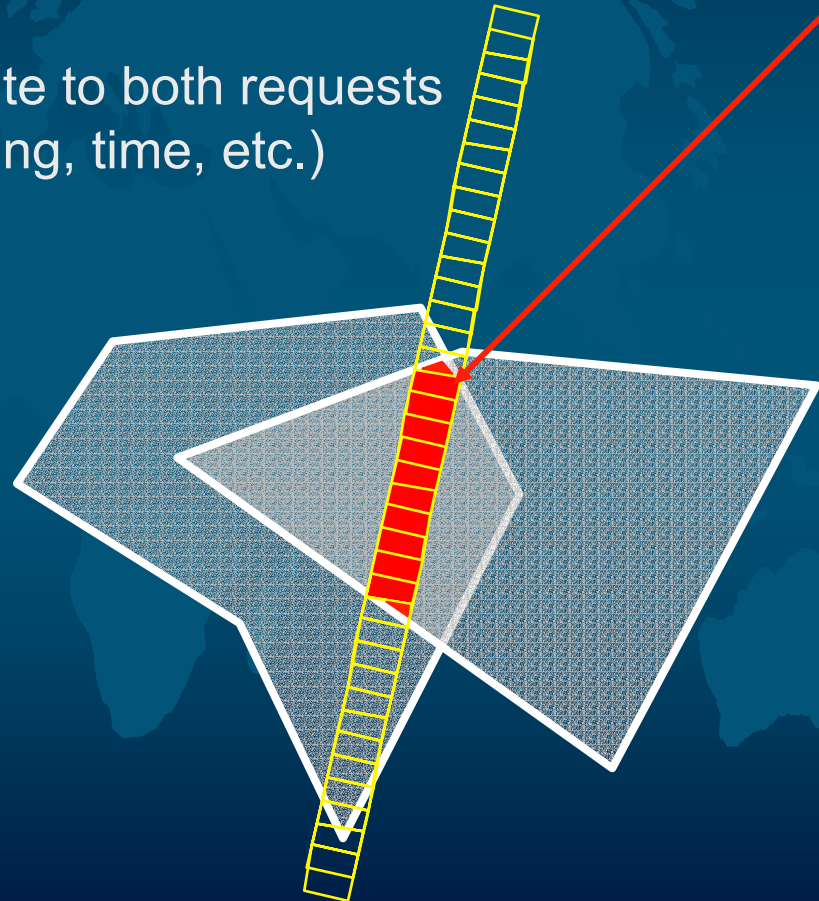
Calculate priority of areas under swath:



Priority of Requests is Additive

Priority = Priority 1 + Priority 2

IF single observation can contribute to both requests
(common constraints: mode, lighting, time, etc.)



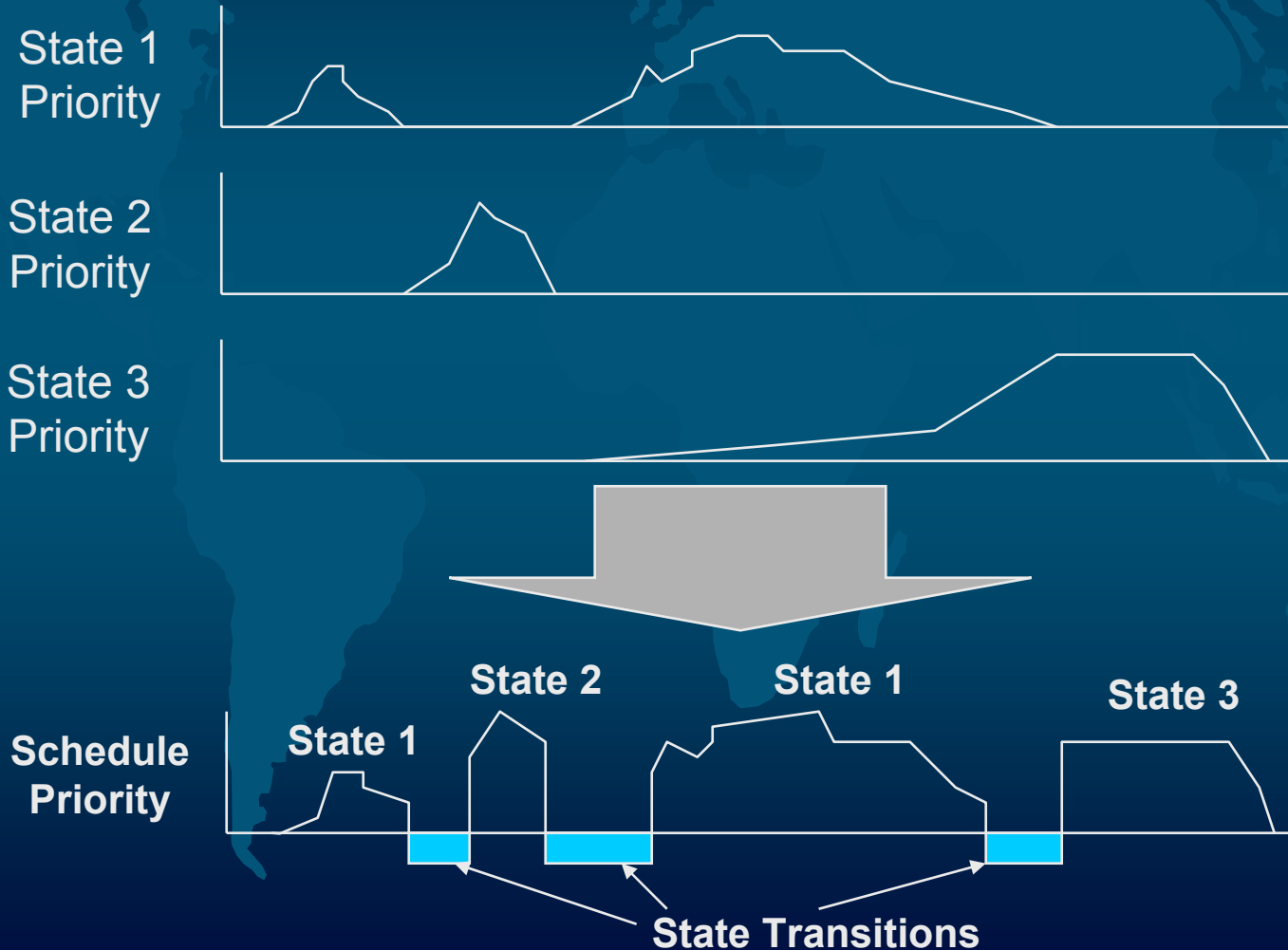
Scheduling Algorithm Approach

1. Create curves of priority vs. time for each potential spacecraft state



Scheduling Algorithm Approach

2. Create schedule with maximum integral priority



ASTER Priority Function

Priority of a point on the Earth's surface:

$$\text{Priority} = f_0 + (f_1 \times f_2 \times L \times f_{11})$$




Priority adjustment factor
for "joysticking"

ASTER Priority Function Terms

- Data Collection Category
 - Engineering, Science, Individual, etc.
- Ground Campaign
- User Category
- Cloudiness
 - Predicted cloudiness, at observation time, vs. users's cloud limit
- Urgency
- $\frac{\text{Remaining Revisits}}{\text{Remaining Observation Opportunities}}$
- $\frac{\text{Remaining Area}}{\text{Requested Area}}$
- Time Since xAR Submission
- Pointing Control
 - If above desired pointing usage curve, downweight observations that request pointing changes

2 ASTER Scheduling Systems

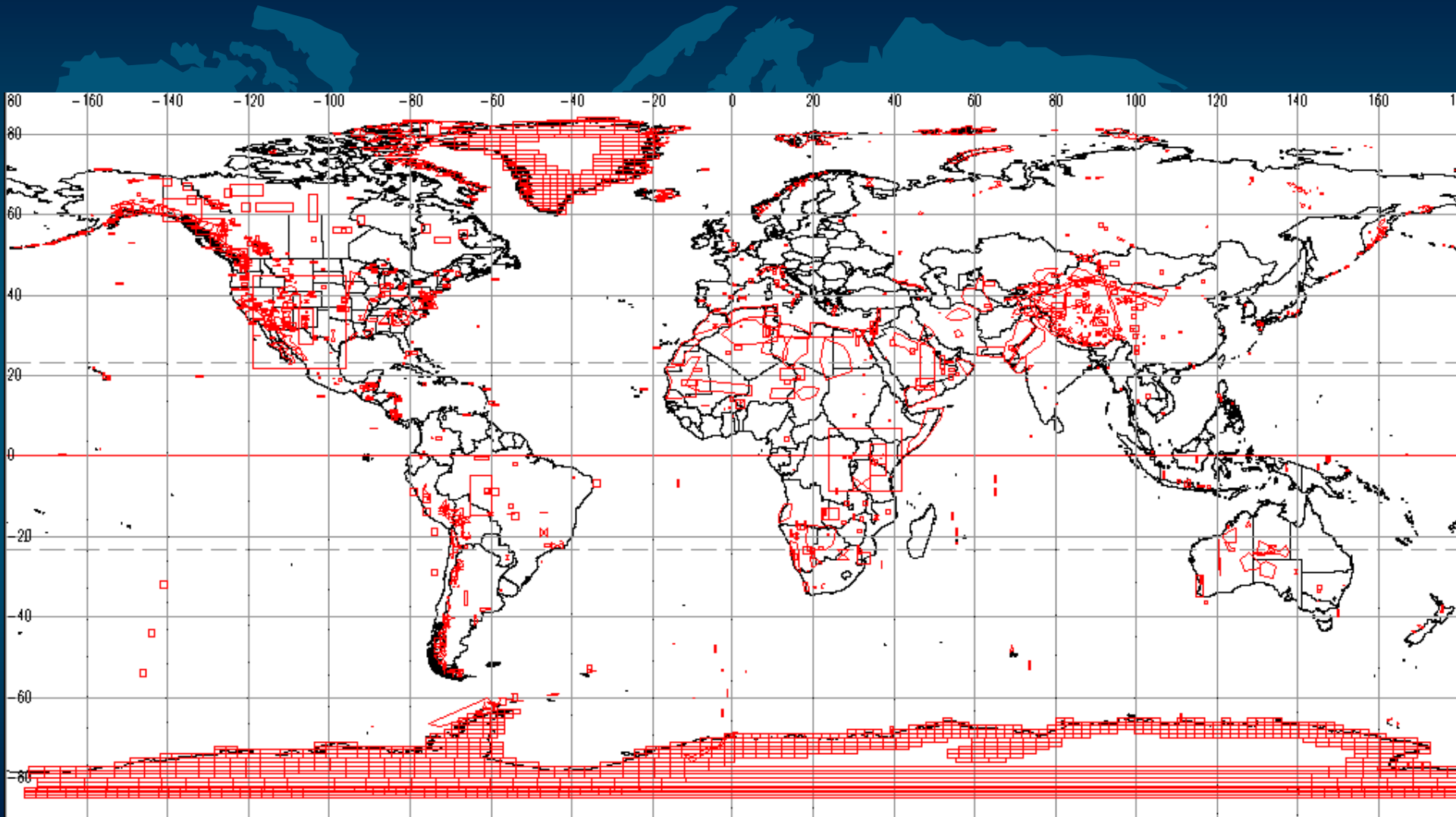
- Independent developments
- ASTER Ground Data System Scheduler in Tokyo
 - Generates ASTER schedule once per day
 - Based on JPL algorithm
- ASTER Mission Simulator (AMS) at JPL
 - Second generation system
 - Intended for mission planning

- 
- Generates schedules
 - Simulates clouds
 - Performs observations and cloud assessment
 - Tracks successful and failed observations

Mission
simulations

AMS Examples

Acquisition Requests



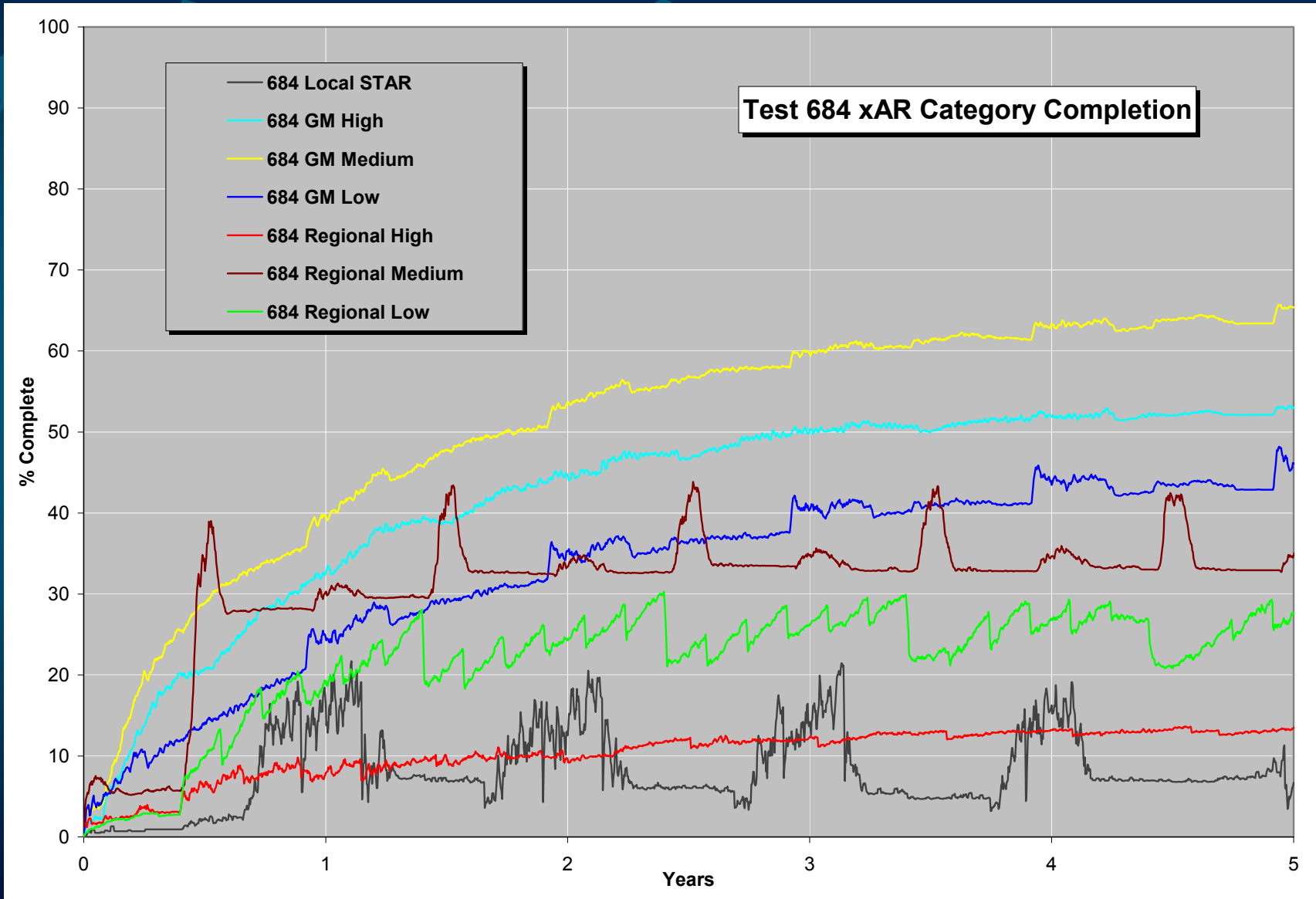
AMS Examples

Number of Times Areas Observed



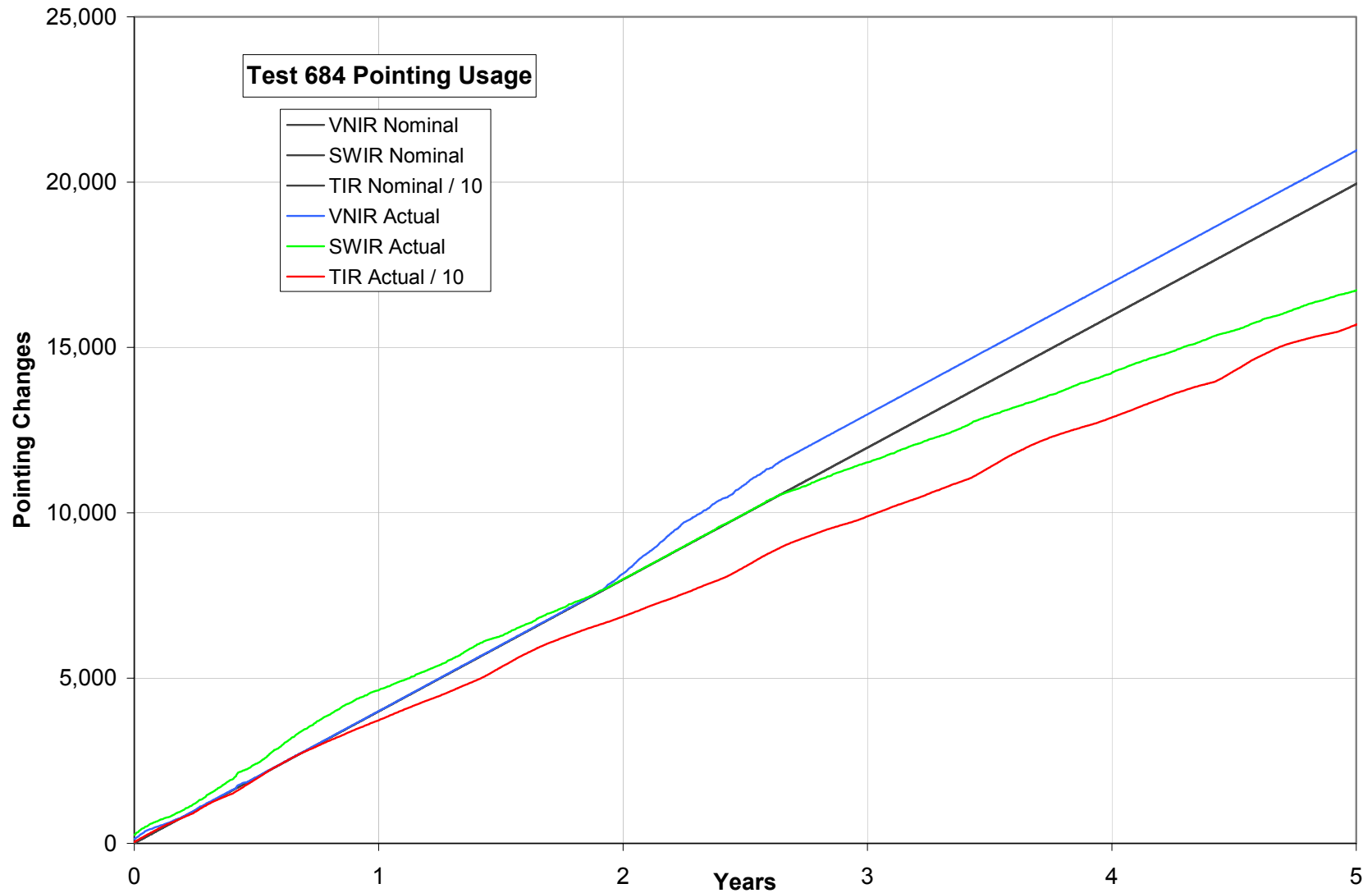
AMS Examples

Completion of Acquisition Request Categories



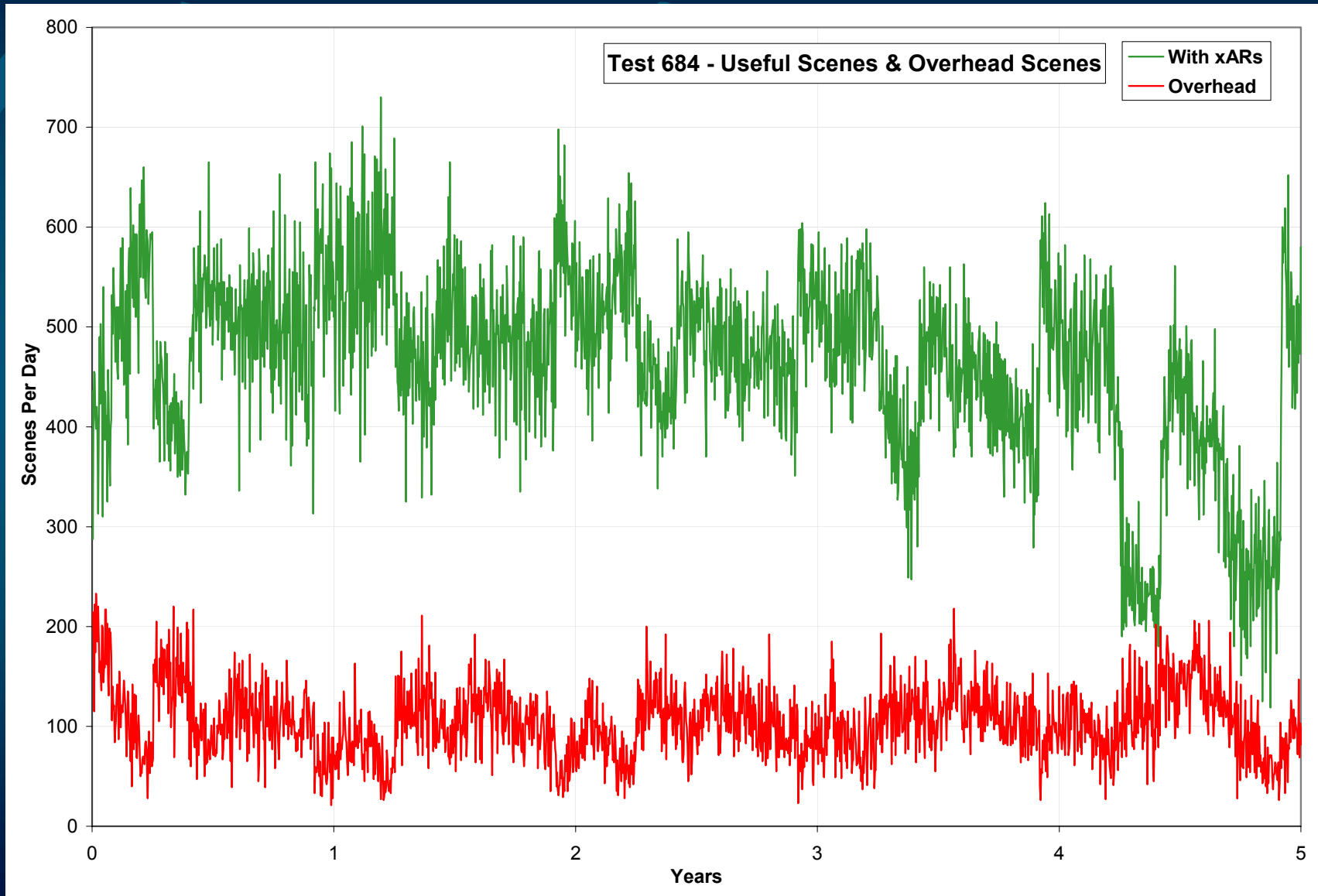
AMS Examples

Use of Pointing Resource vs. Time



AMS Examples

Observed Data vs. Valuable Data



Potential Future Applications

- Other Earth-observing missions
- Planetary missions
 - Mars Reconnaissance Orbiter
- Coordinated and distributed observations
 - Multiple spacecraft or sensors
 - Multiple dynamic targets